Target Recognition in Cluttered Infrared Scenes via Pattern Theoretic Representations and Jump-Diffusion Processes

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Variability in Complex Scenes

- Geometric variability
  - **Position**
  - **Orientation**
  - **Articulation**
  - **Fingerprint (in the Bob Hummel sense)**
- Environmental variability
  - **Thermodynamic variability in infrared**
  - **Illumination variability in visual**
- Complexity variability
  - **Number of objects not known**

Pattern Theory: The Grenander Program

- **Representation:**
  - Incorporate variability in the parameter space
    - **Possibly many nuisance parameters**
  - Model mapping from parameters to data
- **Inference:**
  - Build inference algorithms using the representation
  - Ex.: Markov chain Monte Carlo (jump-diffusion)
- **General notion: avoid “preprocessing” or “feature extraction” as much as possible to avoid loss of information**
  - Recall Biao Chen’s mention of the Information Processing Inequality
- **Apply tools of Bayesian inference to weird things**

Legacy Work

- **Sponsored by**
  - U.S. Army Center for Imaging Science
    (ARO - David Skatrud/Bill Sander)
  - ONR (Bill Miceli)
- **Collaborators**
  - Michael Miller (now at Johns Hopkins)
  - Donald Snyder (Washington Univ.)
  - Anuj Srivastava (now with Dept. of Stat., Florida State)
    - **Airborne targets – radar**
  - Matt Cooper (now with Xerox)
    - **Thermodynamic variability of targets**

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Parameter Space for ATR

- **Parameter space for a single target:**

$$\mathcal{X}(1) = \Re^2 \times [0,2\pi) \times A$$

$$A = \{M2, M60, T62 \ldots\}$$

- **Parameter space for an *n*-target scene:**

$$\mathcal{X}(n) = [\Re^2 \times [0,2\pi) \times A]^n$$

- **Number of targets not known in advance:**

$$\mathcal{X} = \bigcup_{n=0}^{\infty} [\Re^2 \times [0,2\pi) \times A]^n$$

Ingrid's Third Approach

- **Data y, parameters x**
- **Likelihood $p(y \mid x)$**
  - Render infrared scene onto detector plane
  - Model sensor noise effects
- **Prior $p(x)$**
- **Bayesian posterior**

$$\pi(x) \equiv p(x \mid y) \propto p(y \mid x)\, p(x)$$

  - Analytically forboding!
- **Sample via jump-diffusion processes**
  - Jump from subspace to subspace
  - Diffuse to refine estimates within a subspace

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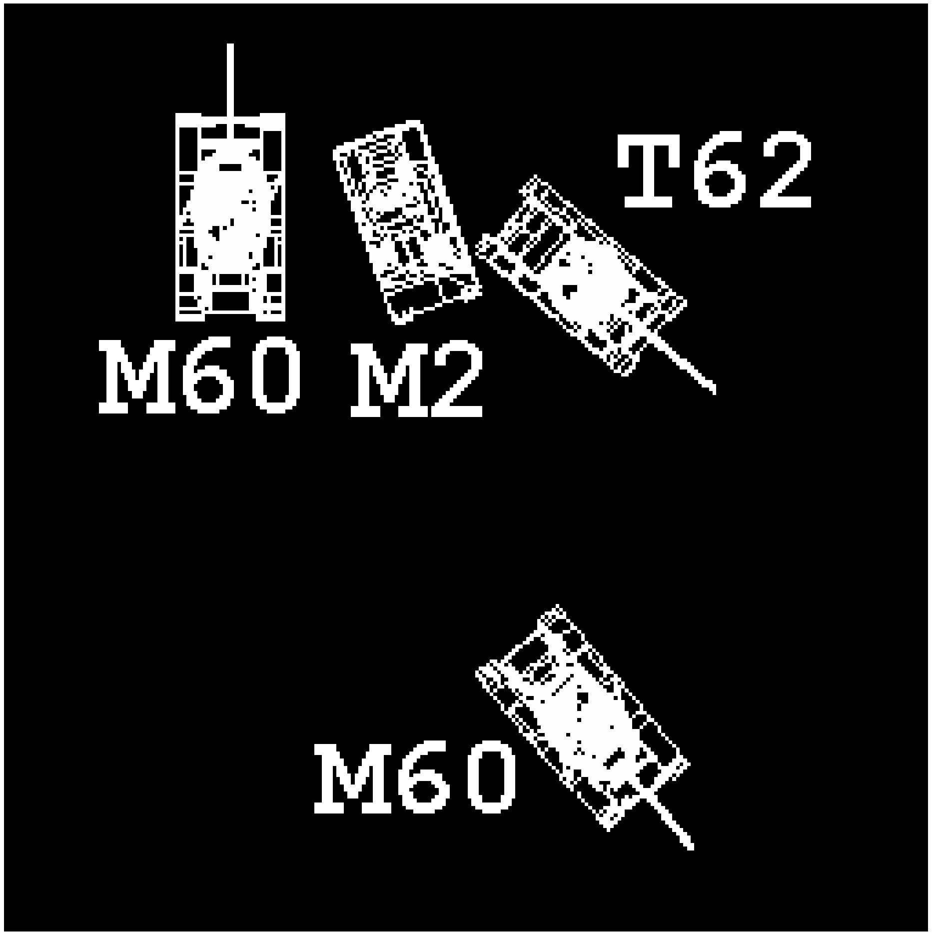
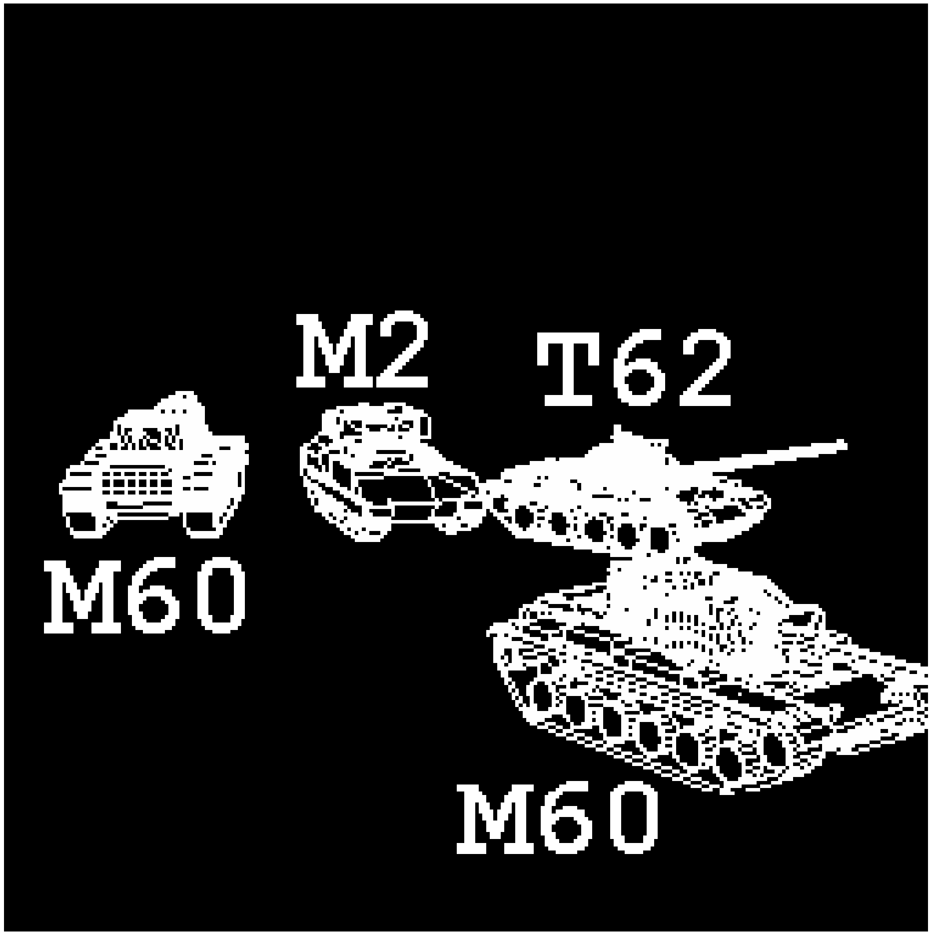
Take Home Message

**Go read
Ulf Grenander's
papers and books.**

They are very cool.

Perspective Projection





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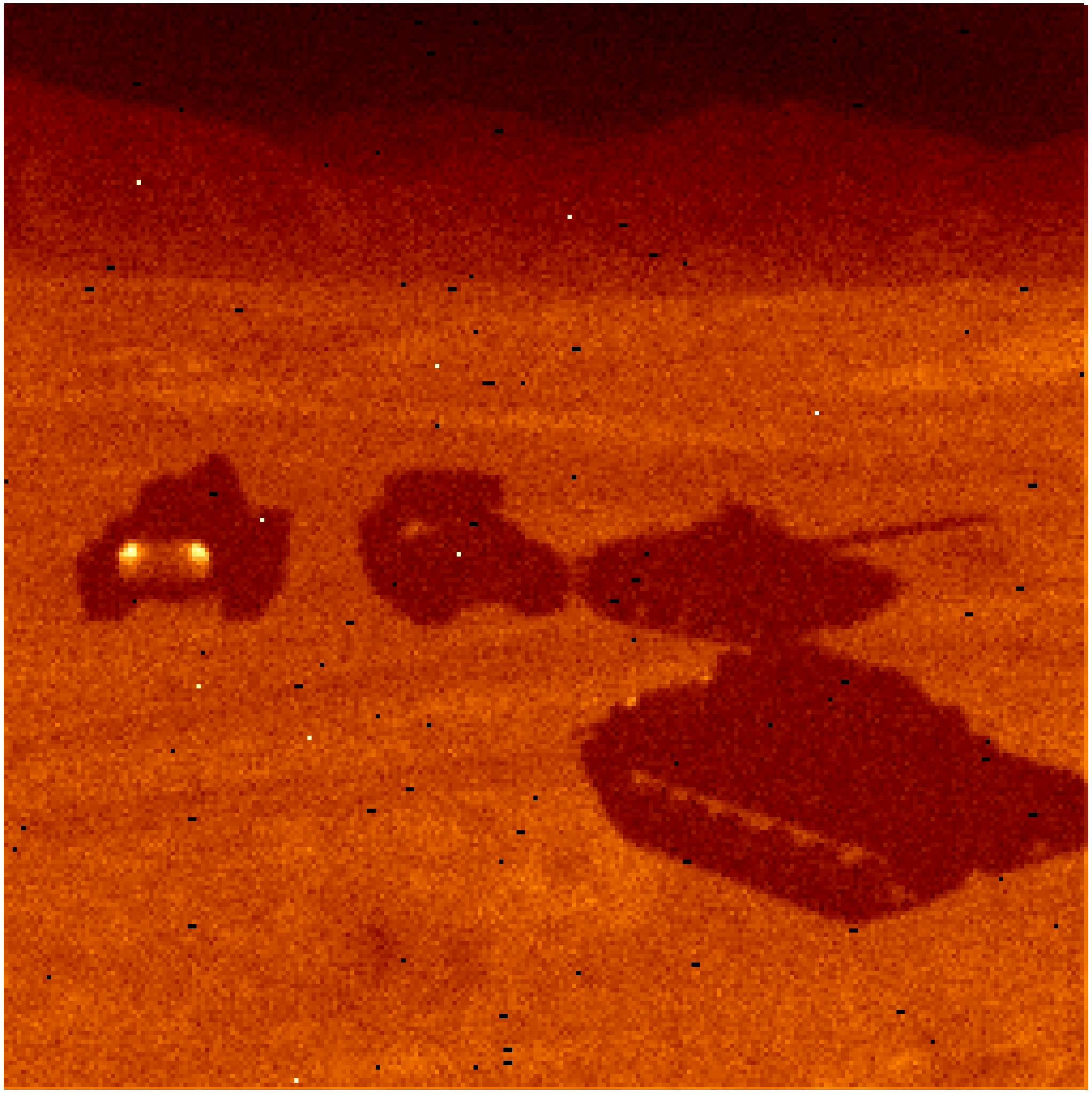
Sensor Effects

Optical PSF

Poisson Photocounting Noise

Dead and Saturated Pixels



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FLIR Loglikelihood

- **CCD loglikelihood of Snyder, Hammoud, and White**

$$L_{CCD}(y \mid \lambda) = -\sum_i \mu(i) + \sum_i y(i) \ln \mu(i)$$

where $\mu(j) = \sum_j \mathrm{psf}(i \mid j)\lambda(j)$

- **Cascade with** $\mathrm{render} : x \rightarrow \lambda$

$$L(y \mid x) = L_{CCD}(y \mid \mathrm{render}(x))$$

- **Sensor fusion natural; just add loglikelihoods**

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Langevin Processes Process

- **Write posterior in Gibbs form:** $\pi(x) = \exp\{H(x)\}/Z$

- **Consider a fixed number of *N* targets and target classes**
- **Simulate Langevin diffusion:**

$$dX_N(\tau) = \nabla_{X_N}\{H(X_n(\tau))\} + dW_N(\tau)$$

- **Distribution of** $X_N(\tau) \xrightarrow{\tau\to\infty} \pi_N(x_n)$

- **Computed desired statistics from the samples**
- **Generalizes to non-Euclidean groups like rotations**
- **Gradient computation**
  – Numeric approximations
  – Easy and fast on modern 3-D graphics hardware

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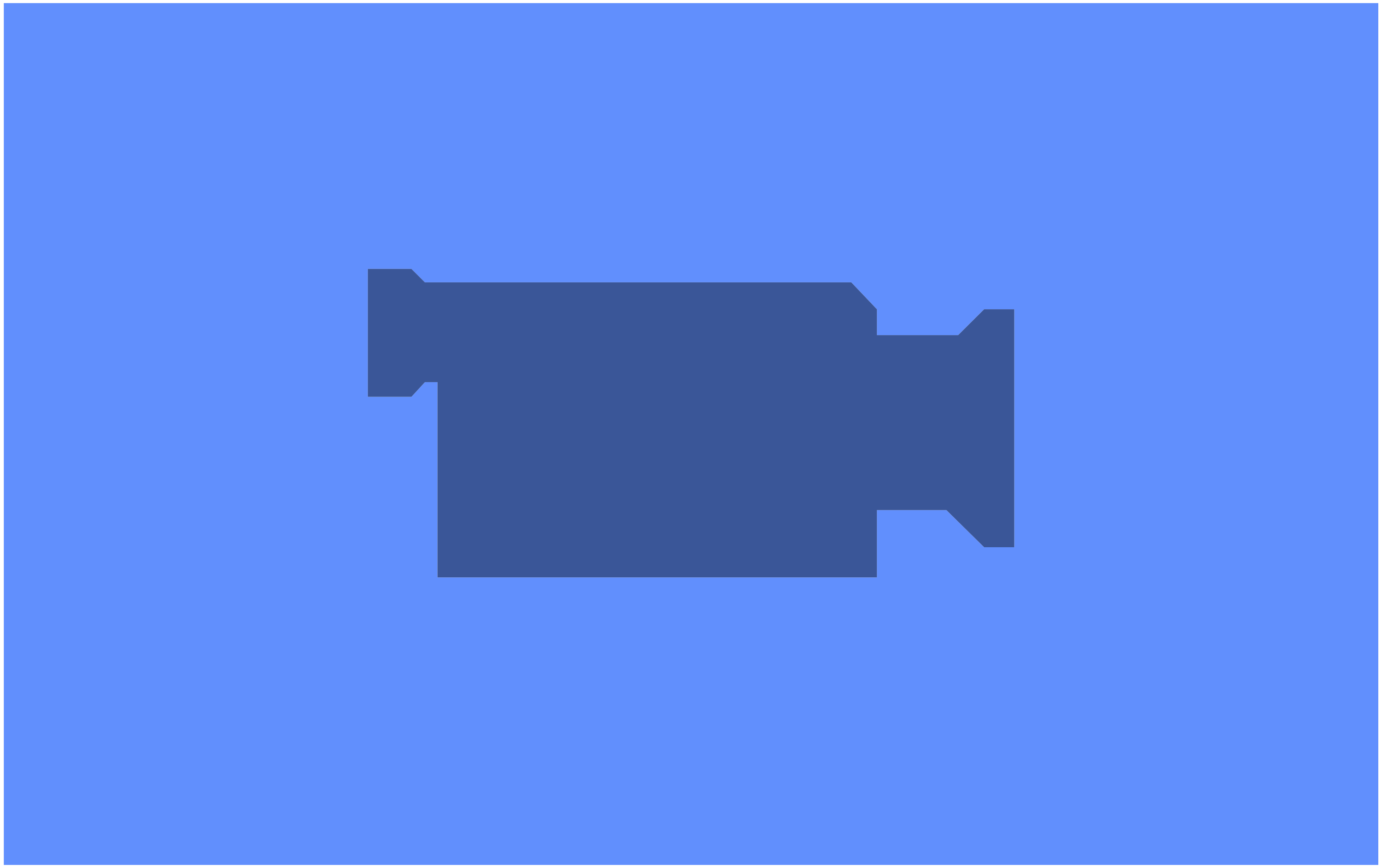
Diffusion Example on AMCOM Data



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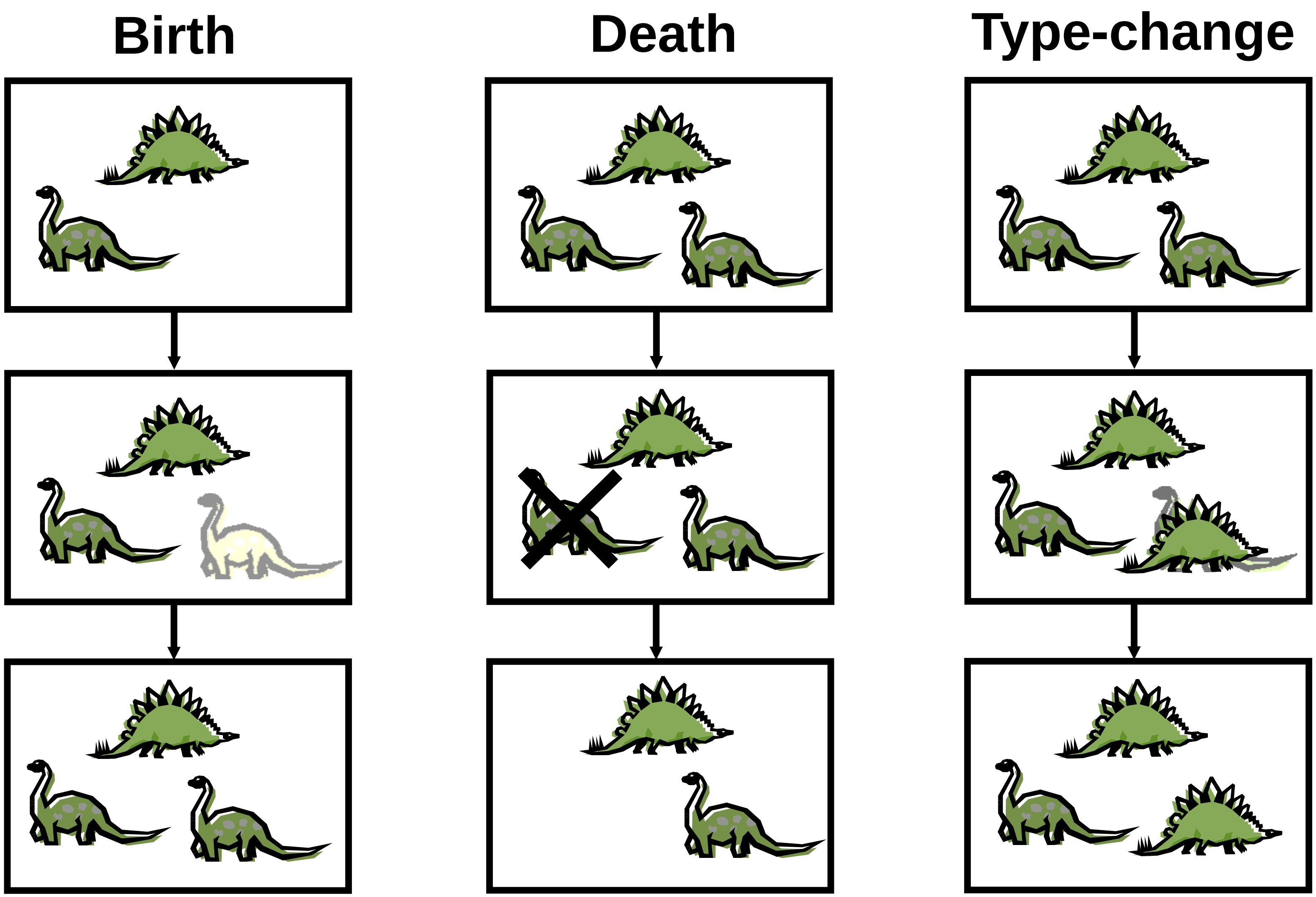
Jump Moves



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Helpful Properties of Jump Processes

- **Jump at exponentially distributed times**

$$\mathcal{T}^{1}(x) = \{\textbf{states reachable from } x\}$$

$$\mathcal{T}^{-1}(x) = \{\textbf{states from which } x \textbf{ can be reached}\}$$

- ***Move reversability*: $\mathcal{T}^{1}(x) = \mathcal{T}^{-1}(x)$**
- ***Connectedness*: can go from any point to any other in a finite number of jumps**
- **Detailed balance (in discrete form)**

$$\pi(x)\Pr(x \rightarrow z) = \pi(z)\Pr(z \rightarrow x)$$

(continuous form slightly more complicated)

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Jumping Strategies

- **Gibbs**
  - Sample from a restricted part of the posterior
- **Metropolis-Hastings style**
  - Draw a "proposal" from a "proposal density"
  - Accept (or reject) the proposal with a certain probability

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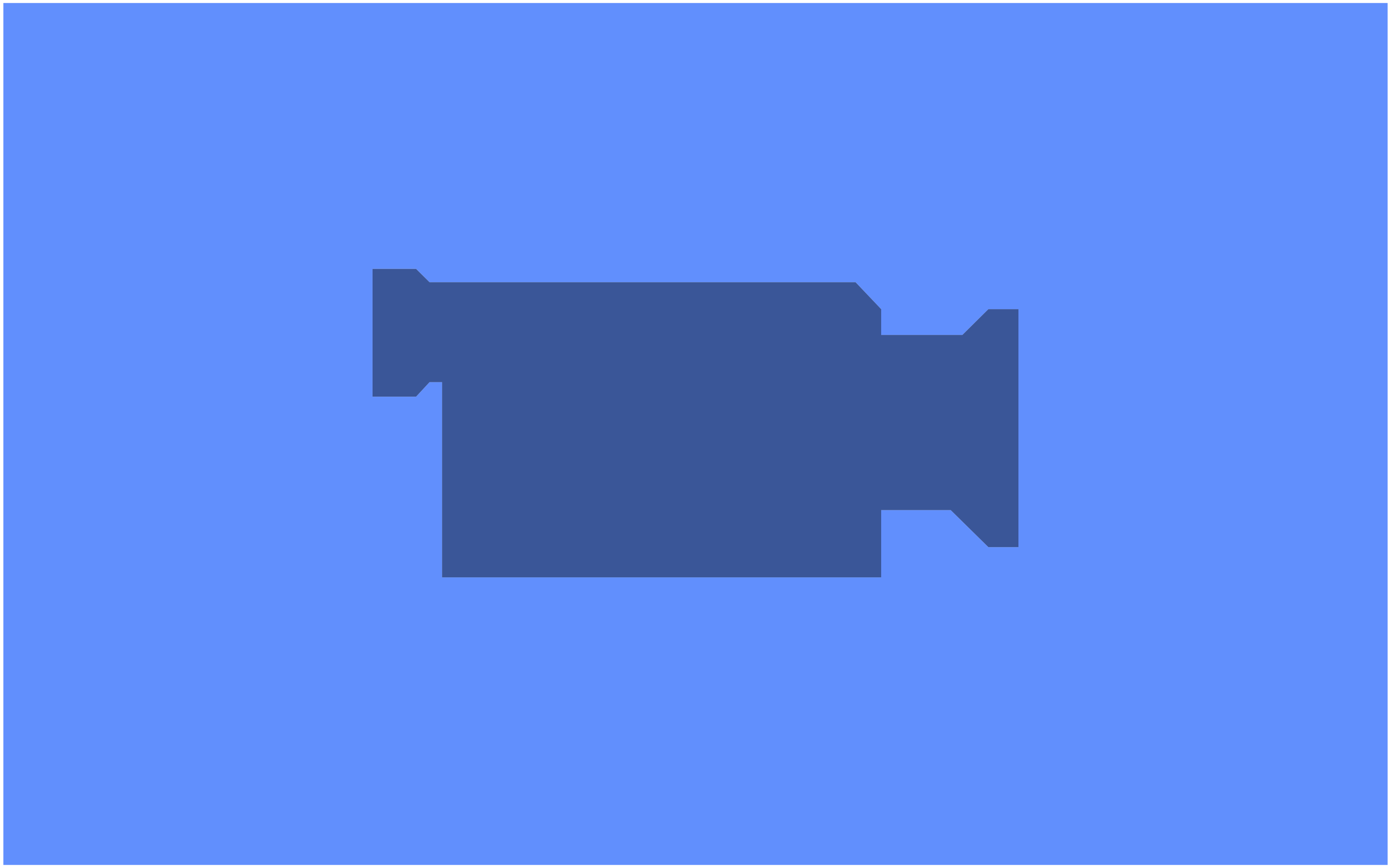
Example Jump-Diffusion Process



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How to Model Clutter?

- **Problem: Algorithm only knows about tanks (which Bob doesn't like anyway), and will try to explain everything with tanks!**
  - Cows, swimming pools, school buses
- **Solution (?): Let the algorithm use *flexible representation* in addition to rigid objects**
  - Blobs: Simple connected shapes on the lattice to represent *structured* clutter
  - Could use active curves, level set methods (Clem Karl), active polygons (Hamid Krim)
  - Clutter might be interesting in its own right!

Random Sampling for Blobs

- **Set of jump moves**
  - –Add a pixel along the boundary
  - –Remove a pixel along the boundary
  - –Keep the blob a blob
- **Pick move based on posterior probability**

Blob Estimation Examples

M60 spreading

M60 decaying

Ship decaying

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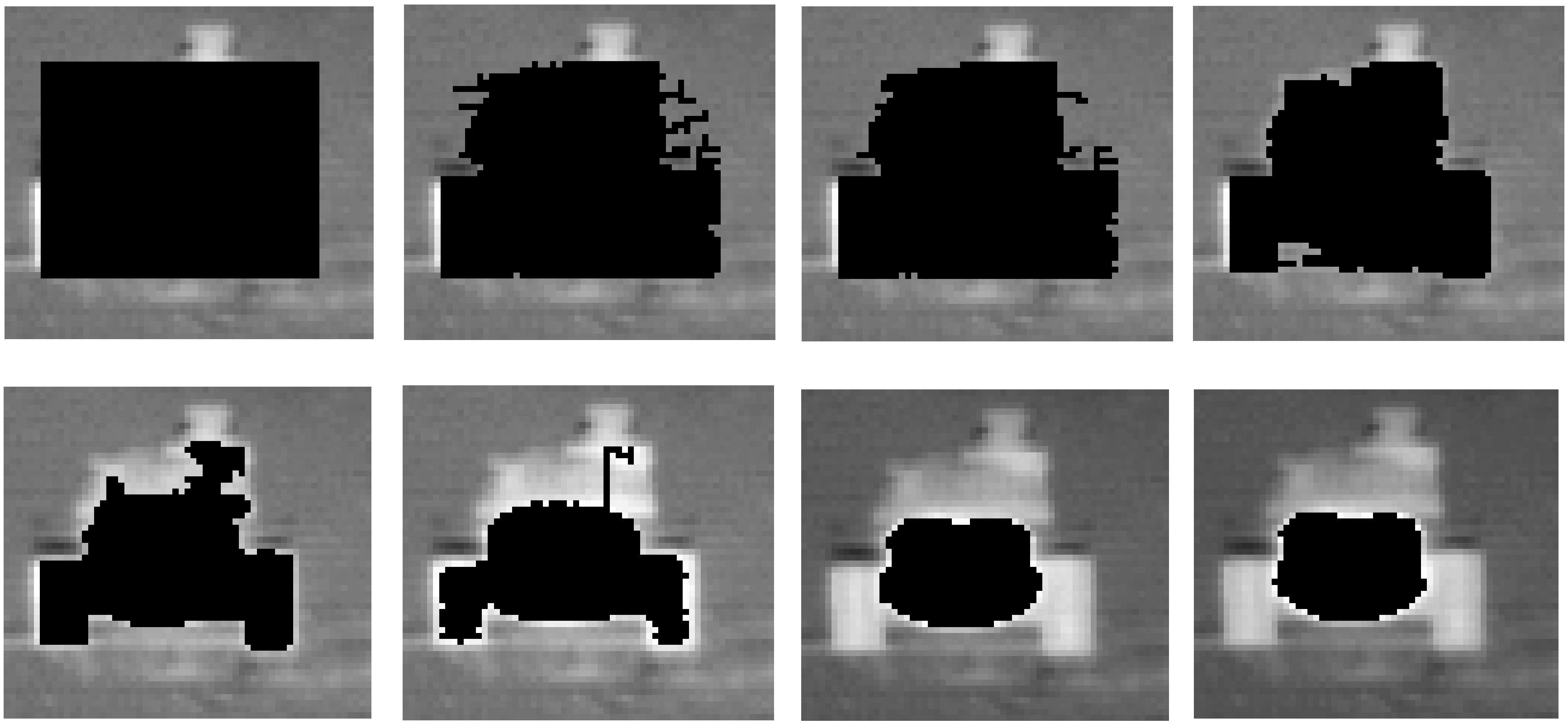
NVESD M60 Example



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Saccadic Detection

- **Current implementation "births" specific target types**
- **May be better to birth simple shapes, and later change them to more specific target types (clutter or target)**
- **Example:**
  - Birth squares
  - Deform into rectangles
  - Then jump to more detailed targets

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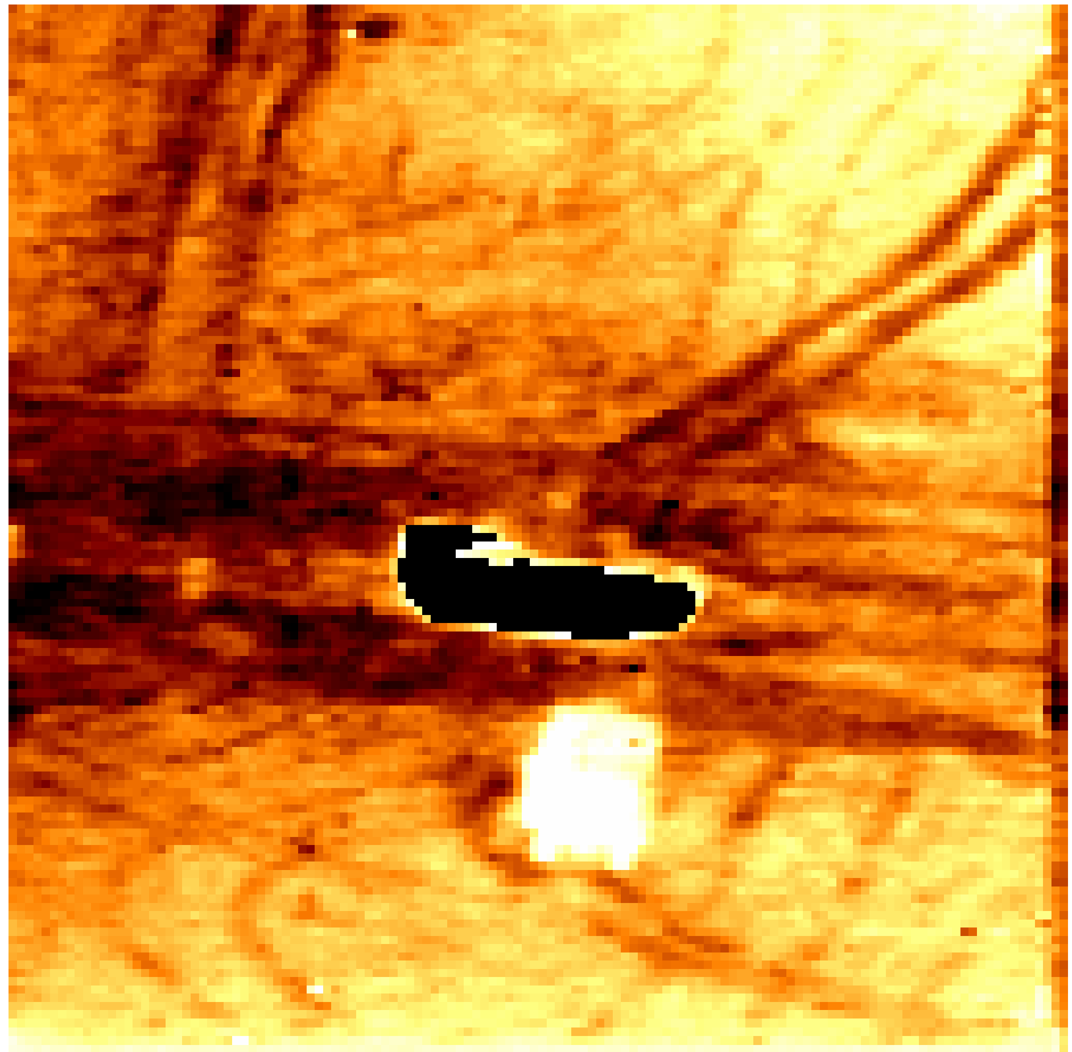
AMCOM Data Ex.: Finding Tank 1

Initial Detection

Low-dimensional refinement

High-dimensional refinement

Equilibrium



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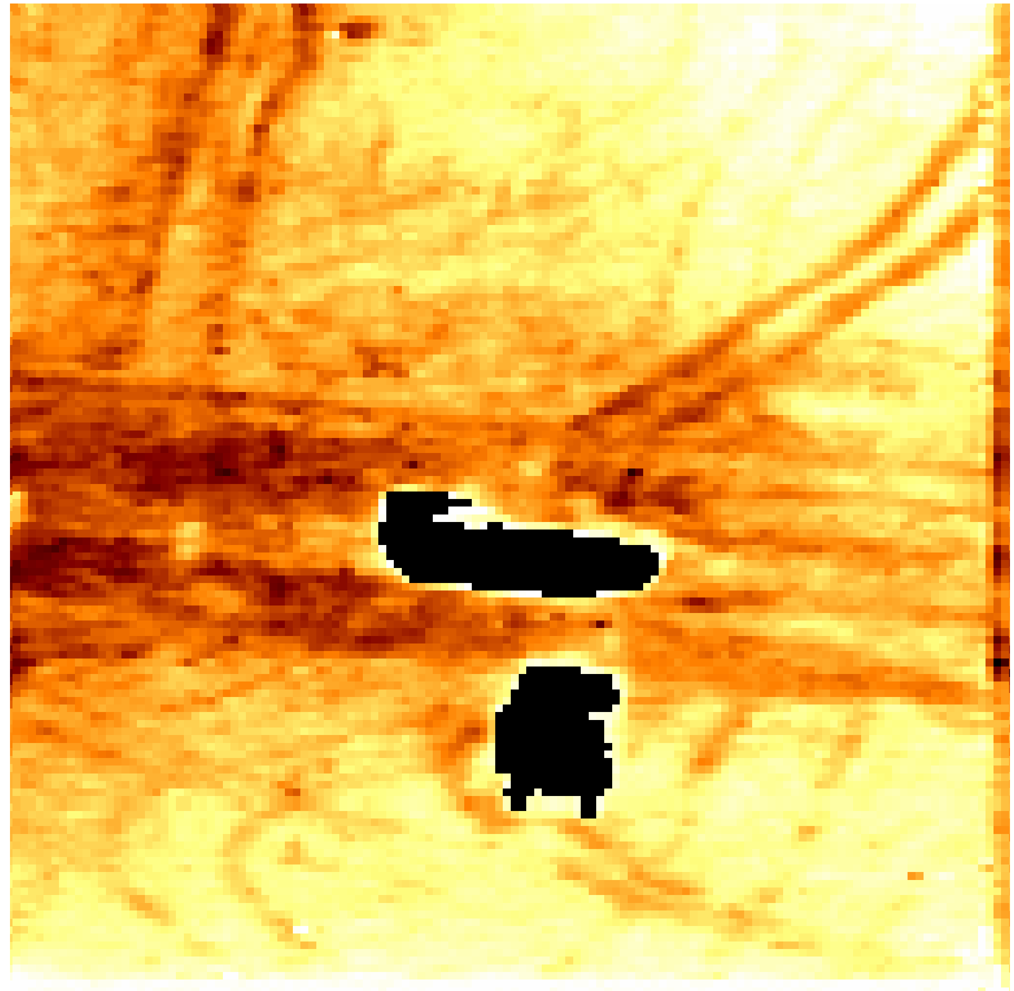
AMCOM Data Ex.: Finding Tank 2

Initial Detection

Low-dimensional refinement

Equilibrium



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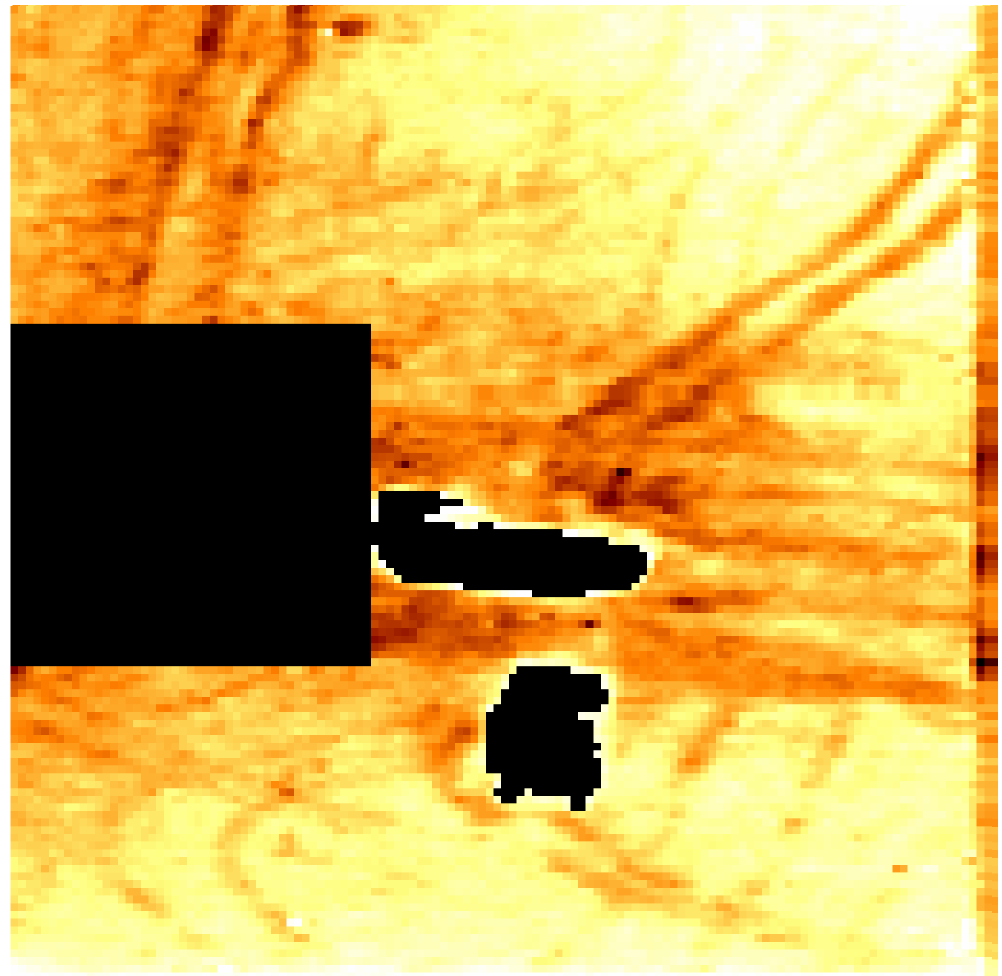
AMCOM Data Ex.: Finding ?????

Initial Detection



Low-dimensional refinement

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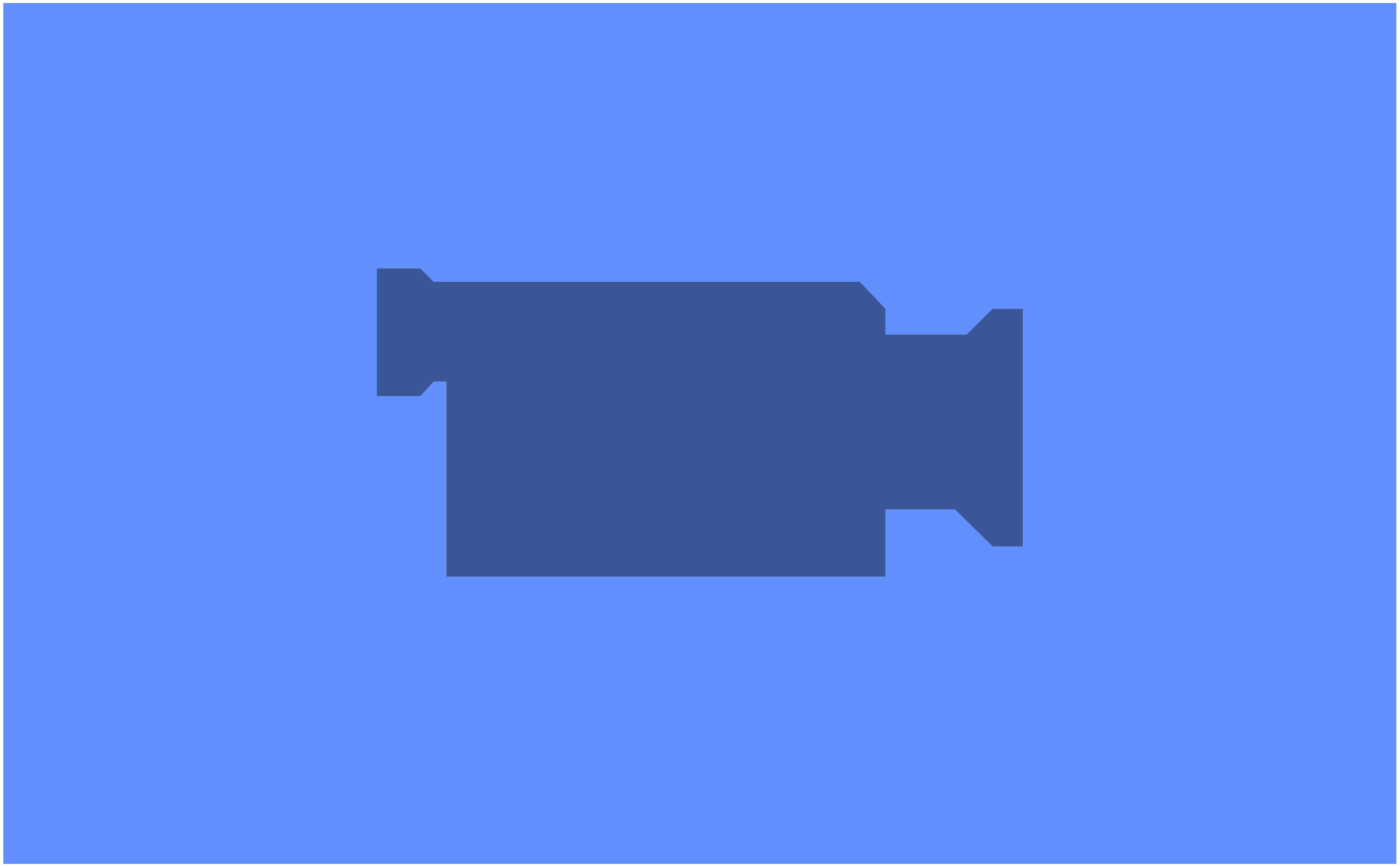
Factory Example



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Unified Algorithm

- **Extended jump moves**
  - Saccadic $\leftrightarrow$ blob
  - Saccadic $\leftrightarrow$ rigid
  - Blob $\leftrightarrow$ rigid
  - Break/combine blobs
  - Change rigid target types
- **Difficulty: Make parameters make sense between representation types**

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